Evidence of Localized States in InGaN/GaN Double Heterostructures

Mee-Yi Ryu, Phil Won Yu* and Jin Soo Kim
Department of Information and Communications, Kwangju Institute of Science and Technology,
Kwangju 500-712, Korea, *E-mail: pwyu@kjist.ac.kr
Eun-joo Shin, Joo In Lee, and Sung Kyu Yu
Optoelectronics Group, Korea Research Institute of Standards and Science, Taejon 305-600, Korea
Eun Soon Oh, Yong Jo Park, Hyeong Soo Park, and Tae Ill Kim
Photonics Laboratory, Samsung Advanced Institute of Technology, Suwon 440-600, Korea

We have performed the optical studies of localized excitons in InGaN/GaN double heterostructures (DHs) by means of photoreflectance (PR), photoluminescence (PL), and cathodoluminescence (CL). The sample was grown on a (0001)-oriented sapphire substrate by metal-organic chemical vapor deposition. The nominally undoped 22 nm wurtzite $In_{0.18}Ga_{0.82}N$ epilayer was grown on 2 μm GaN epilayer and capped with about 0.1 μm GaN epilayer. The PR and PL spectra of InGaN/GaN DHs at 10 and 300 K are shown in Fig. 1. The PR and PL spectra were composed of several emission bands. For the first time, we obtained the PR signals attributed to discrete transition levels in the InGaN layer. The PR spectrum in the range from 2.8 to 3.3 eV was analyzed by the low-field PR line-shape function, a third derivative functional form. The optimum fitting was made assuming the six energy levels at both 10 and 300 K. The PL spectrum at 10 K is also separated six emission bands by the peaks with Gaussian distribution. We consider that these six emission bands in PL spectrum are attributed to a radiative recombination of excitons localized at different potential minima, whose transition energies are obtained from the PR spectrum. The transition energies of the PR spectrum at 10 K are higher than those of the PL spectrum with the amount of 60 to 90 meV. These energy differences, which are referred to as the Stokes shift, are caused by a potential inhomogeneity in the InGaN layer.

In order to figure out the spatial distribution of the emission, the CL measurements were performed at 80 K. A wide area (12 x 12 μm^2) integrated scanning CL spectrum of InGaN/GaN DHs is shown in Fig. 2 (a). The CL peak energy from InGaN epilayer is 2.88 eV at 80 K. However, CL peak energies for InGaN epilayer obtained from limited spot areas (~ 200 x 100 nm^2) varied from position to position, as shown in Fig. 2 (b). A wide area integrated CL peak was found to consist of several emissions having various peak energies. The appearance of strong higher energy CL peaks at 3.25 eV indicates that some spot areas are composed of a GaN-rich part. This shows there exist several structures having different net band gap energies. These structures can act as quantum-disks or quantum-dots depending on the lateral size.

Figure 3 shows monochromated scanning CL images of InGaN/GaN DHs taken at wavelengths of (a) 357 nm (3.472 eV), (b) 381 nm (3.253 eV), (c) 408 nm (3.038 eV), and (d) 430 nm (2.882 eV). A careful comparison of Figs. 3 (a) – 3 (d) indicated following results; (i) bright areas and dark areas in Fig. 3 (a) correspond complementary to dark areas in Fig. 3 (d) and bright areas in Fig. 3 (b), respectively, (ii) bright areas in Fig. 3 (a) are composed of a GaN-rich part surrounded by an InN-rich part, (iii) bright areas consist of emissions from about several hundreds nm to a few μm in lateral size of real spaces, and (iv) approximately 50 % of the entire areas are bright at 430 nm (2.882 eV),

which correspond to the wide area integrated CL peak wavelength. These results can be interpreted assuming the existence of InGaN quantum-disks having various InN molar fractions due to a compositional fluctuation whose lateral interval is smaller than 200 nm. This value is the spatial resolution of the system. The CL results together with PR and PL results also indicated there exist several structures having different net band gap energies due to compositional inhomogeneity.

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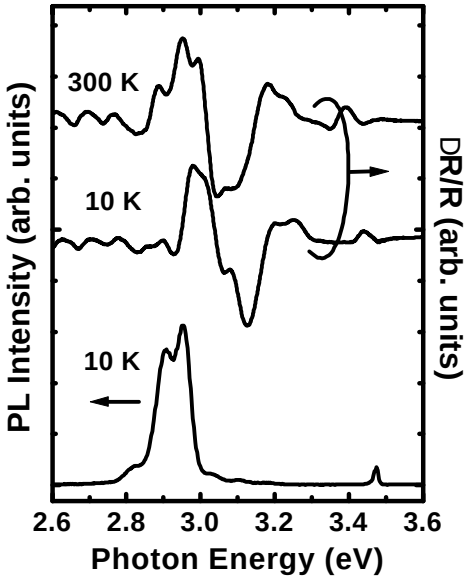

Fig. 1. PR and PL spectra of InGaN/GaN DHs at 10 and 300 K.

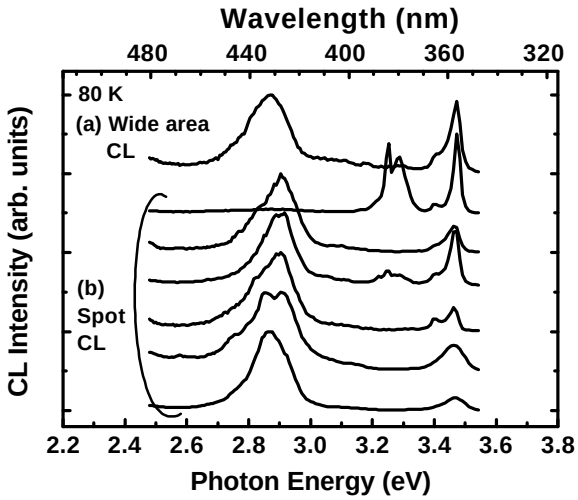

Fig. 2. CL spectra of InGaN/GaN DHs at 80 K.

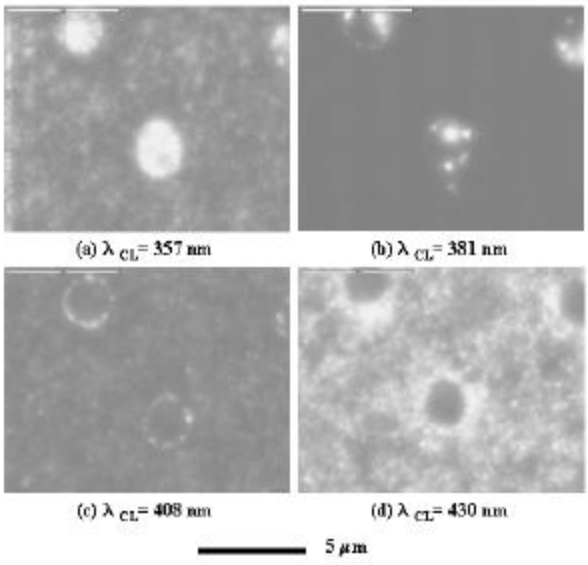

Fig. 3. Monochromated scanning CL images of InGaN/GaN DHs.